

SOUTH

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FISHERIES

**ANALYSIS FOR RESTORATION OF WATER QUALITY AND
SUPPLY FOR THE FISHERY AT YATES PONDS,
SOUTH DAKOTA**

**South Dakota
Department of
Game, Fish and Parks
Wildlife Division
Joe Foss Building
Pierre, South Dakota 57501-3182**

**Completion Report
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**ANALYSIS FOR RESTORATION OF WATER QUALITY AND
SUPPLY FOR THE FISHERY AT YATES PONDS, SOUTH DAKOTA**

by

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PREFACE

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Executive Summary

Yates Ponds are located near Cheyenne Crossing in the Black Hills of South Dakota. Nearly 1000 brown and brook trout exist in the ponds, representing one of the highest population densities of naturally spawning trout in the Black Hills. Inflow to the ponds has historically been limited to spring flow and localized groundwater infiltration. During an extended dry period in 1984, however, water levels in the ponds began to decrease. To help offset the declining water levels, the flow from Icebox Creek was diverted into the ponds. Prior to the diversion of the creek, aquatic macrophyte populations showed a seasonal cyclic growth and decay pattern. Following the diversion, the aquatic macrophyte densities increased dramatically in the ponds and became a year-round problem. The impact of highway 14A, which runs along the east shoreline of the ponds, is also a concern.

The primary objective of this project was to develop an understanding of nutrient and water budgets in Yates Ponds. This knowledge is needed to develop methods to reduce excessive aquatic macrophyte populations. Insight is also needed to determine if the ponds can sustain desired water elevations without receiving the surface inflow from Icebox Creek. Field measurements and lab analyses were used to identify nutrient sources, determine the amount of phosphorus entering the system, and develop a long-term water budget for the pond system. Insight gained from these results can be used to develop proposed remediation solutions for problems involving water quality, water supply, sedimentation, and the impact of highway 14A at Yates Ponds.

The ponds are the outfall point of a 2.1 square mile forested catchment composed mainly of steep hills and canyon walls. The 1.3-acre pond system is made up of a series of three small ponds. The first pond has acted as a sediment trap for the other two ponds and has subsequently filled with sediment. Flow from Icebox Creek is currently channeled through all three ponds. A combination of surface water and localized ground water springs and seeps supply water to the ponds.

Initial stages of the project included development and implementation of water quality monitoring and flow measurement procedures. Field data for phosphorus, water temperature, and turbidity were used to develop a nutrient budget. Groundwater observation wells reflected interactions between the groundwater and water levels in the pond. Surface inflow and outflow were periodically measured at several locations. An evaporation pan was installed and a weather observation station was set up to collect climate data. These data were then used to develop a water budget. Water quality measurements were analyzed using a HACH field kit and were verified by a commercial testing laboratory.

Nutrient sampling results indicated a seasonal trend in phosphorus concentrations in the system. The general trend in both surface and groundwater was the same, with the highest concentrations detected in mid to late winter and the lowest concentrations occurring during mid to late summer. Comparing samples from Icebox Creek and spring inflow indicated that phosphorus concentrations in the surface inflow were approximately 51 % higher than in groundwater.

Results of the water budget analysis indicated that under normal conditions, the pond system could sustain the required water levels necessary to support the fishery without flow from Icebox Creek. This was verified during an experimental re-routing of Icebox Creek around the ponds during 2000 and 2001. At least one dry period has occurred in the past where the pond water levels decreased enough to threaten the fishery. Management flexibility is needed that would allow Icebox Creek to be diverted around the ponds in normal and wet conditions, and would also allow the creek to flow through the pond system during dry conditions. An example would be a gate system that is normally closed to divert Icebox Creek around Yates Ponds, but could also be opened to allow Icebox Creek to flow into the ponds during periods of inadequate spring and groundwater flow. Another approach would be to construct a small managed wetland system upstream of the pond inlet. A designed and managed wetland could reduce sources of sediment and phosphorus carried into the ponds from Icebox Creek. With an effective wetland in place, the creek could be allowed to flow into the ponds during

periods when subsurface flow is inadequate, without degrading the water quality of the system.

To minimize the nutrient and sediment loads from Highway 14A, it may be necessary to construct curb and gutter along the section of roadway adjacent to the main pond. The roadway runoff could be routed to either the small wetland or towards Raspberry Gulch, around the north boundary of the pond.

Acknowledgement

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1.0 Introduction

Yates Ponds are located near Cheyenne Crossing in the Black Hills region of western South Dakota. The ponds are an important natural trout fishery and are a popular catch and release fishing location. The ponds contain nearly 1000 brown and brook trout, representing one of the highest population densities of naturally spawning trout in the Black Hills (Erickson, 1996). Inflow to the ponds has historically been limited to spring flow and groundwater infiltration. During an extended dry period in 1984, however, water levels in the ponds began to decrease. To help offset the declining water levels, the flow from Icebox Creek was diverted into the ponds. Prior to the diversion of the creek, aquatic macrophyte populations showed a seasonal cyclic growth and decay pattern. Following the diversion, the aquatic macrophyte densities increased dramatically in the ponds and became a year-round problem.

The primary objective of this project was to develop an understanding of nutrient and water budgets in Yates Ponds. This knowledge is needed to develop methods to reduce excessive aquatic macrophyte populations. Insight is also needed to determine if the ponds can sustain desired water elevations without receiving the surface inflow from Icebox Creek.

2.0 Site Description

Yates Ponds is the outfall point of a 2.1 square mile forested catchment composed mainly of steep hills and canyon walls. Basin slopes are often in excess of 20%, with channel slopes ranging from 3% to 10%. The pond system is made up of a series of three small ponds (Figure 1). The first pond has acted as a sediment trap and has subsequently been almost entirely filled with sediment, becoming a small wetland system. Since 1984, flow from Icebox Creek has been diverted to the second pond through a 16" diameter metal culvert. A short channel connects the second and third ponds, which total 1.3 acres in size. Ponds 2 and 3 then drain into Spearfish Creek through controlled outlets. Water supply to the ponds is from a combination of surface water, localized groundwater springs, and in-pond seeps. Summers are warm and dry,

and winters are cold. The average annual precipitation is 22 inches, primarily occurring during thunderstorms in spring and early summer, and during winter snowfall. The average annual potential evaporation rate is 40 inches per year.

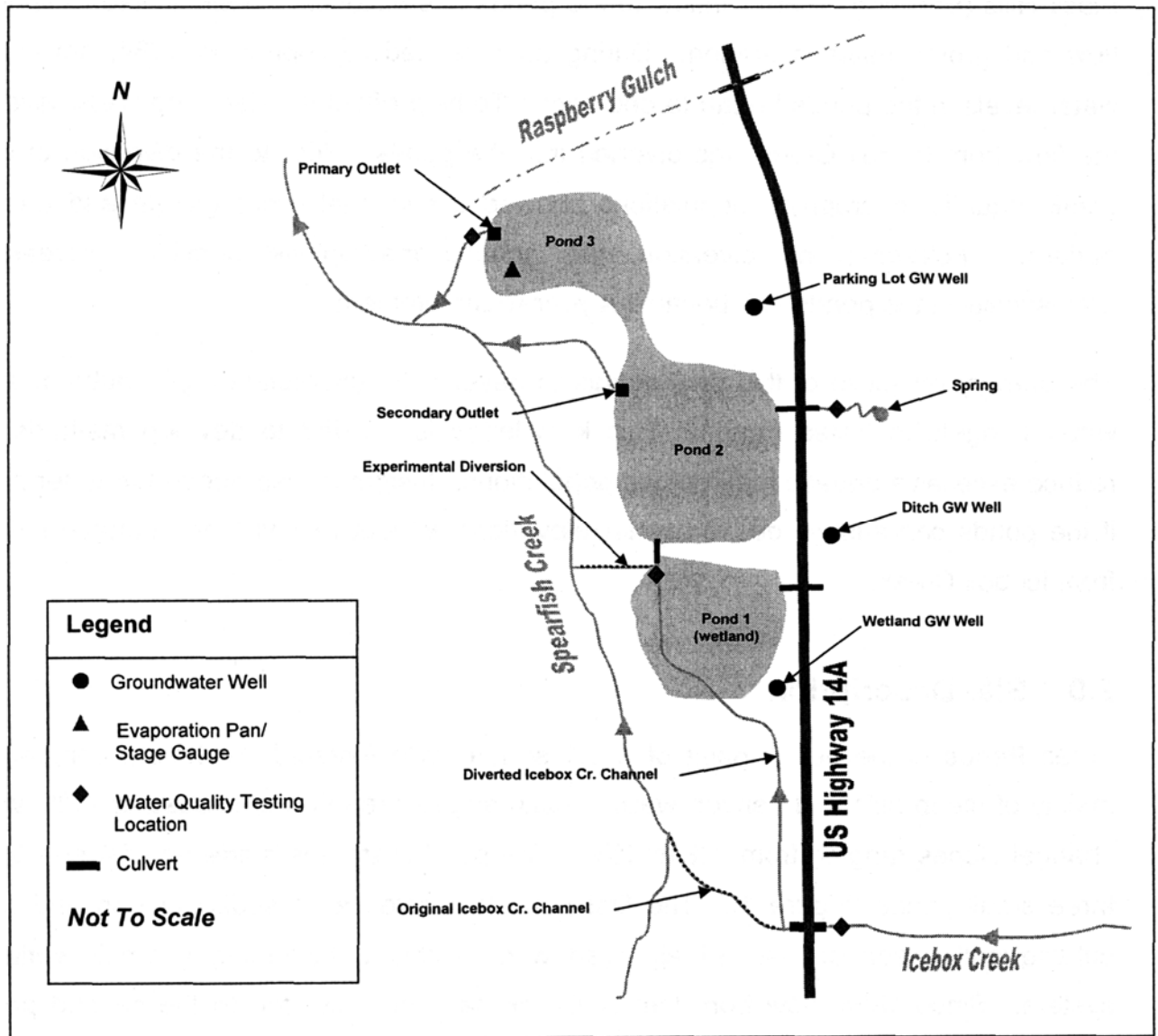


Figure 1. Yates Ponds Site Map

3.0 Project Objectives

The data collection and analysis were designed to address the following objectives:

- 1) To quantify surface and groundwater nutrient loads in the water supplies to the pond and to develop a nutrient budget.
- 2) To quantify surface and groundwater flows and to develop a water budget.
- 3) To quantify sediment sources to the pond and identify potential mechanisms to reduce sediment delivery.
- 4) To evaluate the impact of complete diversion of Icebox Creek inflow on pond water surface elevation.
- 5) To estimate the impacts of reduced nutrient loads and surface diversions on aquatic macrophyte densities.
- 6) To develop baseline information to be used to design a new roadway alignment and sub-grade structure that will allow for under-grade flow of springs.

4.0 Analyses and Results

Nutrient Budget

Phosphorus was used as the main indicator for water quality in Yates Ponds because it is frequently the limiting nutrient in plant growth in natural systems (Kadlec and Knight, 1996; Cooke et al., 1993). Field data for concentrations of ortho-phosphorus as phosphate were collected in the surface and groundwater and were analyzed for both seasonal and spatial trends. These measurements were taken using a HACH field-testing kit, following testing procedures outlined in the HACH kit manual.

Energy Systems Laboratory, a commercial testing laboratory in Rapid City, was used to verify the phosphorus measurements. The testing lab concluded that the amount of phosphorus in the Yates Ponds system was at or near the detection limits of the HACH field kit and the lab equipment used to verify the results. For this reason, the results will be used for comparative or relative analysis only. For instance, it is reasonable to compare phosphorus levels in the groundwater and surface water, but the measured values may not represent exact, or absolute, phosphorus concentrations in the water.

Nutrient sampling results indicated a seasonal trend in phosphorus concentrations in the system (Figure 2). The general trend in both surface and groundwater was the same, with the highest concentrations detected in mid to late winter and the lowest concentrations occurring during mid to late summer. Comparing samples from surface inflow and spring inflow indicated that phosphorus concentrations in the surface inflow

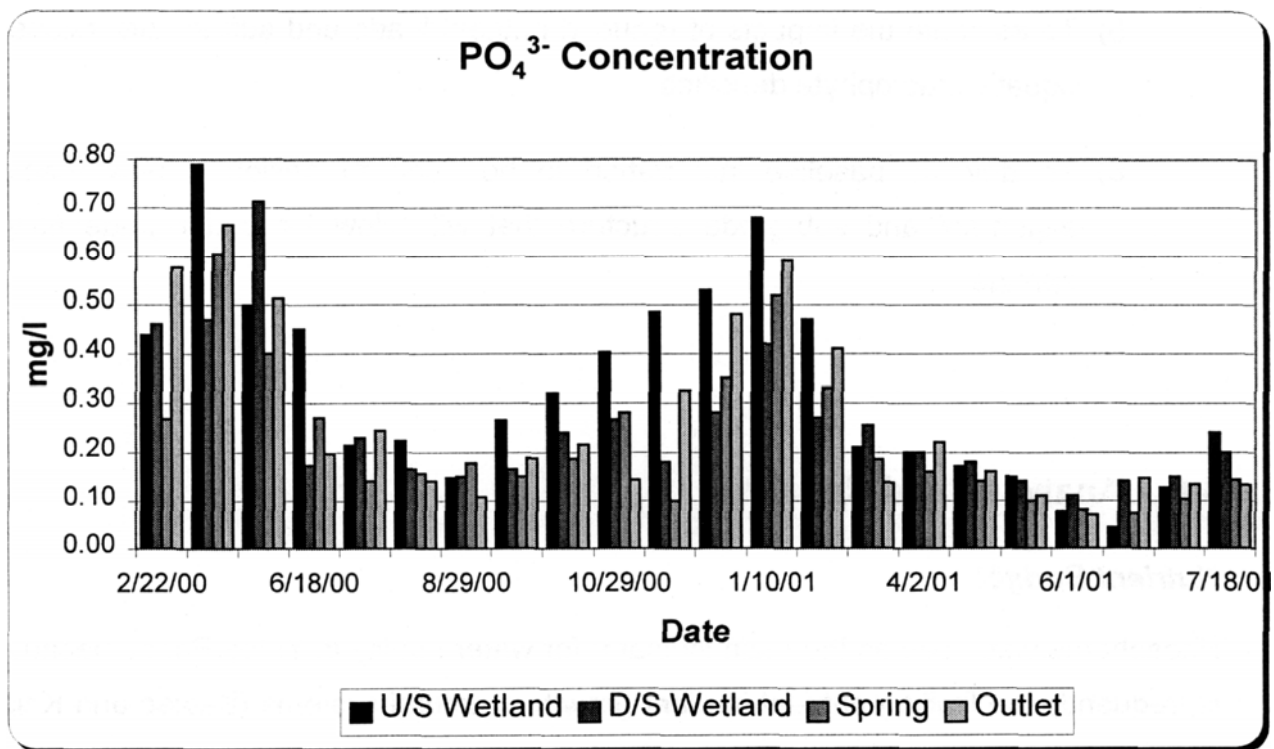


Figure 2: Nutrient Budget: Comparison of phosphorus concentrations at four locations

were approximately 51% higher than in groundwater (Table 1). There was an average decrease of only 3% in phosphorus concentrations in surface water from upstream to downstream of the wetland area. Most of the decrease in phosphorus through the wetland occurred during late summer and winter, when the highest concentration in Icebox Creek occurred (Table 1).

Table 1: Percent Change in P043" Concentration (mg/l)

Date	Icebox Creek	Spring	Change (%)	Upstream Wetland	Downstream Wetland	Change (%)
2/22/00	0.438	0.268	64	0.438	0.460	5
03/02/00	0.790	0.605	31	0.790	0.470	-41
04/27/00	0.498	0.400	25	0.498	0.713	43
06/18/00	0.450	0.270	67	0.450	0.173	-61
06/30/00	0.213	0.140	52	0.213	0.230	8
08/06/00	0.223	0.157	43	0.223	0.165	-26
08/29/00	0.148	0.177	-17	0.148	0.150	2
09/24/00	0.265	0.150	77	0.265	0.165	-38
10/08/00	0.320	0.187	71	0.320	0.240	-25
10/29/00	0.403	0.280	44	0.403	0.267	-34
11/26/00	0.485	0.100	385	0.485	0.180	-63
12/22/00	0.530	0.350	51	0.530	0.280	-47
01/10/01	0.680	0.520	31	0.680	0.420	-38
02/08/01	0.470	0.330	42	0.470	0.270	-43
03/06/01	0.210	0.185	14	0.210	0.254	21
04/02/01	0.200	0.160	25	0.200	0.200	0
04/28/01	0.170	0.140	21	0.170	0.180	6
05/17/01	0.150	0.100	50	0.150	0.140	-7
06/01/01	0.077	0.080	-4	0.077	0.110	43
06/17/01	0.043	0.073	-41	0.043	0.140	223
07/04/01	0.128	0.103	23	0.128	0.150	18
07/18/01	0.240	0.143	67	0.240	0.200	-17
		Average	51		Average	-3

*Surface inflow from Icebox Creek was diverted after 8/6/00

One other important comparison that can be made is water temperature versus phosphorus concentration. Table 2 shows water temperature along with phosphorus concentration at the pond outlet. For this project, it was assumed that the outlet conditions were the same as conditions inside the ponds.

Table 2: PO43" Concentration and Temperature At Pond Outlet

Date	Phosphorus Concentration (mg/l)	Water Temperature (°C)	Date	Phosphorus Concentration (mg/l)	Water Temperature (°C)
02/22/00	0.58	7	12/22/00	0.48	4
03/02/00	0.67	6	01/10/01	0.59	3
04/27/00	0.51	7	02/08/01	0.41	6
06/18/00	0.20	12	03/06/01	0.14	10
06/30/00	0.24	16	04/02/01	0.22	10
08/06/00	0.14	12	04/28/01	0.16	11
08/29/00	0.11	13	05/17/01	0.11	11
09/24/00	0.19	9	06/01/01	0.07	14
10/08/00	0.22	7	06/17/01	0.15	15
10/29/00	0.14	10	07/04/01	0.13	16
11/26/00	0.33	4	07/18/01	0.13	14

*Surface inflow from Icebox Creek was diverted after 8/6/00

Water Budget

A comprehensive water balance for a natural pond includes the following terms: (Gupta, 1989)

$$P + Q_{SI} + Q_{GI} - E - Q_{SO} - Q_{GO} - \Delta S - n = 0 \quad \text{Equation 1}$$

where

- P = precipitation
- Q_{SI}, Q_{GI} = surface and groundwater inflow into the system
- E = evaporation
- Q_{SO}, Q_{GO} = surface and groundwater outflow from the system
- Δs = change of storage volume within the boundary
- n = term often used to reflect error or uncertainty

To develop a practical water balance for Yates Pond, processes that are relatively insignificant or can not be reliably measured must be deleted from the comprehensive equation.

There are three significant sources of water supply into the pond system. Icebox Creek supplies surface water into the ponds. A second source of inflow is a spring that surfaces on a hillside to the east of the pond. The third source of water is from groundwater infiltration into the pond. Standard current meter techniques were used to measure inflow from Icebox Creek as well as outflow from the pond.

A weir plate at the culvert inlet (Figure 1) was initially used to measure the spring flow. However, the culvert had deteriorated to the point where water was able to flow around the weir plate into the culvert and through several small holes in the culvert barrel section. Other sampling locations and methods were considered, but the nature and location of the spring made it impossible to sample anywhere except at the culvert inlet. Therefore, the calculated spring flow is most likely an underestimation of the actual flow. A table showing the collected spring flow data is shown in Appendix 1.

Three piezometers were installed to monitor groundwater elevations. The site is too complex to infer actual groundwater inflow or outflow from the pond from a few piezometers. However, the groundwater elevations provided an indication of the relative wetness or dryness of the near surface groundwater system, and the variation related to significant rainfalls and seasonal cycles.

A weather station was installed at the site to measure evaporation and precipitation over the pond surface. Evaporation was also measured using an evaporation pan at the pond. The impact of precipitation and evaporation on the pond water balance were found to be insignificant when compared to other flows, and were therefore not used in the water budget calculations. For example, an evaporation rate of 0.25 inches per day yields a loss of only 0.014 gpm, compared to observed outflows often in excess of 300 gpm. A table showing the evaporation and precipitation data that was collected is included in Appendix 1.

The change of storage in the pond system is relatively small over periods longer than a day because of the small volume of the pond and because of the design of the outlet structures that automatically maintain a relatively constant water level in the ponds.

Therefore, the water balance equation (Equation 1) can be reduced to $Q_{SI} + \text{net } Q_{GI} = Q_{SO}$. Spring flow was included with groundwater in the net Q_{GI} term, to avoid increasing the uncertainty in the water balance equation due to the leaking culvert used to measure spring flow. The uncertainty term (n) can not be explicitly evaluated for this project, and is therefore incorporated in the term for net Q_{GI} , since net groundwater inflow is estimated as the difference between Q_{SI} , and Q_{SO} . This approach is appropriate for this project, and the errors are relatively small compared to the measured surface inflow and outflow.

Discharge measurements were taken approximately every four weeks, resulting in data for surface inflow, net groundwater inflow, and total outflow shown in Table 3. Inflows into the system did not vary significantly through the year, with the exception of snowmelt during the spring thaw. Flow data indicates that Icebox Creek accounted for approximately 55% of the flow into the system up until the diversion on August 6, 2000. Groundwater sources, which include spring flow and underground seeps, supplied the other 45% of the pond inflow. After August 6, 2000 groundwater and spring flow provided 100% of the inflow.

Impact of Surface Water Diversion on Pond Water Level

Flow measurements indicate that groundwater is a significant source of pond inflow (Table 3). To evaluate how well the pond water levels would be sustained without surface flow from Icebox Creek, the creek was temporarily diverted around the main ponds, flowing instead directly into Spearfish Creek (Figure 1). The diversion was in place from August 2000 until August 2001. During this 1-year period, the water level in the ponds was sustained solely by spring and groundwater inflows. The water level in the ponds remained constant both before and during the diversion test at 5312.8 feet above sea level, the height of the overflow weir during testing. However, several more years of measured groundwater flows, plus a review of historic flow conditions, are

needed before the assumption can be made that inflow from subsurface sources alone would sustain adequate pond levels during extended dry periods.

Table 3: Water Budget (gallons per minute)

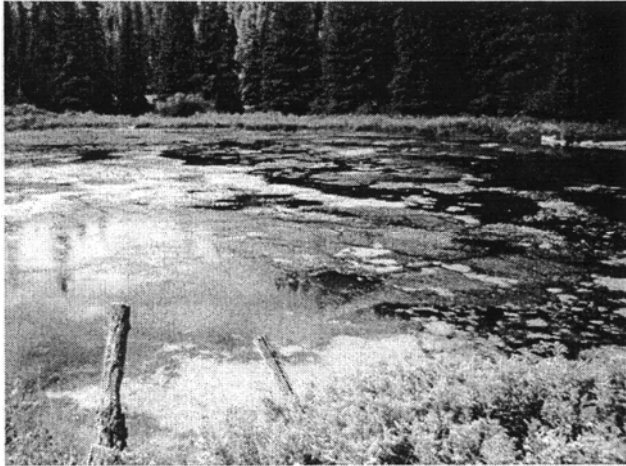
Date	Surface Water Inflow*	Net Groundwater Flow	Total Outflow
05/29/00	1149	970	2119
05/30/00	1160	927	2087
05/31/00	1207	512	1718
06/02/00	938	315	1253
06/04/00	933	411	1345
06/18/00	337	948	1285
06/30/00	334	749	1083
07/23/00	314	716	1029
08/06/00	462	433	895
08/29/00	18	359	377
08/30/00	20	359	380
09/01/00	16	367	382
09/02/00	15	347	362
09/05/00	14	361	375
09/24/00	9	354	363
10/08/00	5	326	331
10/29/00	3	319	322
11/26/00	0	201	201
12/22/00	0	276	276
01/10/01	0	241	241
02/08/01	0	203	203
03/06/01	0	197	197
04/02/01	0	264	264
04/28/01	0	377	377

*Surface inflow from Icebox Creek was diverted after 8/6/00.

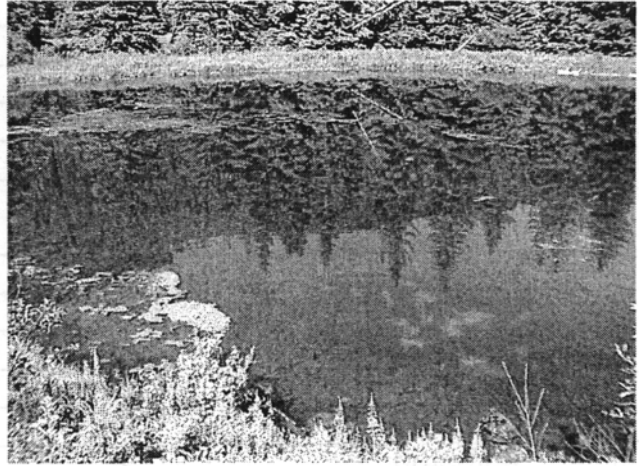
Reduction of Aquatic Macrophyte Density During Diversion

After a year with the experimental diversion in place, macrophyte population and densities appear to have decreased dramatically. Figure 3(a), taken in the summer of 2000, and Figure 3(b), taken in the summer of 2001, show a wide-angle perspective of the middle pond (pond 2 in Figure 1). Before the experimental diversion was in place (August 2000), aquatic algae covered the surface of the pond (Figure 3(a)). Nearly one

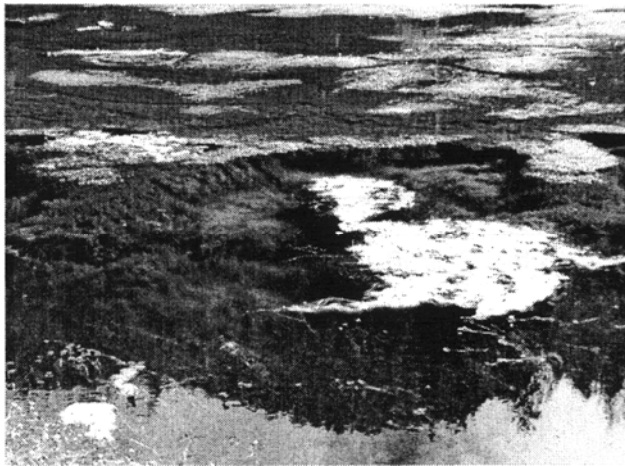
year later (Figure 3(b)), the surface algae is almost nonexistent. The only surface algae that can be seen floating on the pond in Figure 3(b) is a small patch in the upper left portion of the photo. The sharp reflection of the shoreline trees in the cleaner water of Figure 3(b) versus that of Figure 3(a) is an indication of the reduction in dense aquatic vegetation related to the diversion of Icebox Creek.



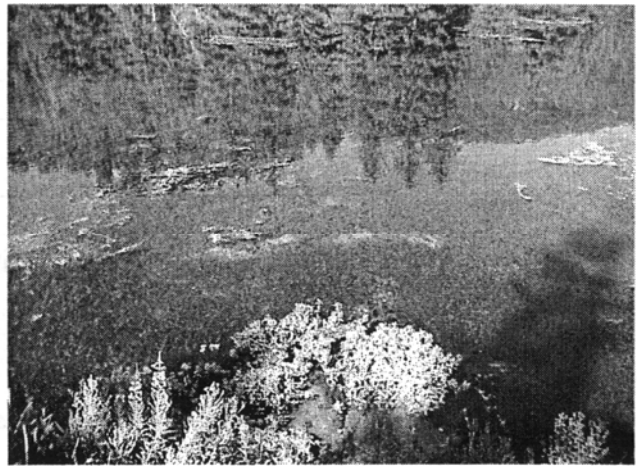
(a)



(b)



(c)



(d)

Figure 3: Comparison of algae before (a & c) and one year after (b & d) experimental diversion

Figures 3(c) and 3(d) show a closer view of the same pond. Figure 3(c) was taken in the summer of 2000, before the experimental diversion. Figure 3(d) was taken during the summer of 2001, one year after the diversion was in place. A large amount of underwater algae is visible in Figure 3(c), but not in Figure 3(d). Looking past the tree shadows in the foreground in Figure 3(d), the bare earth on the bottom of the pond can be seen in some places. Subsequent visual observations during the late summer of 2001 showed a continued decrease in vegetation densities throughout the ponds. Diverting the surface inflow also appeared to decrease the amount of icing on the pond surface during winter months.

Sediment

Sediment inflow and deposition is known to be a potential problem in the ponds, since the upper pond has filled in despite efforts in the past to remove sediment deposits. Periodic measurements of turbidity in pond inflow were used to estimate sediment loads during normal streamflow conditions. Turbidity was measured in Formazine Attenuation Units (FAU), using the procedures outlined in the HACH test kit manual. Test results indicated that during normal flow, there was little or no turbidity present in the water flowing into the pond from Icebox Creek or the spring flow (Table 4). This result is not surprising, since normal inflow velocities are too slow to carry significant amounts of sediment. Therefore, the majority of sediment entering the ponds is probably transported during high streamflow associated with significant rainfall-runoff events. The most likely sources of the sediment load are the roadways near the ponds and along Icebox Creek, with additional sediment coming from minor channel scour and hill slope erosion.

At this time, it appears that the small wetland system upstream of the primary pond is trapping much of the incoming sediment. However, it is not known how well the wetland acts to trap the sediment under high flows. There is currently no buffer between Highway 14A and the pond, so it is probable that most of the sediment on the road surface is washed into the ponds during rainfall events. Much of the roadway sediment

comes in the form of gravel and salts used for winter highway maintenance, but there is also a significant problem with asphalt sloughing off the road into the pond.

Table 4: Turbidity (FAU)

Date	Icebox Cr.	Spring	Pond Inlet
02/22/00	9	2	1
03/02/00	2	0	0
04/27/00	10	3	3
06/18/00	4	0	0
06/30/00	2	1	2
08/06/00	8	0	0
08/29/00	0	0	0
09/24/00	3	3	3
10/08/00	2	0	1
10/29/00	0	0	7
11/26/00	1	0	4
12/22/00	1	1	3
01/10/01	1	0	4
02/08/01	2	1	3
03/06/01	4	3	4
04/02/01	3	3	4
04/28/01	4	3	3
05/17/01	2	1	2
06/01/01	2	1	3
06/17/01	2	2	3
07/04/01	4	2	5
07/18/01	1	3	5

Roadway

Water balance data and the presence of groundwater infiltration inside the pond indicate that the current spring flow and groundwater flow under the highway is adequate for sustaining pond levels during the hydrologic conditions of 2000 and 2001. The roadway does not appear to be interfering with the drainage of spring flow into the pond. Monitored groundwater levels (Table 5) indicate that the majority of groundwater that enters the ponds flows under the road along the edge of the main pond. For

comparison, the water elevation in the ponds was 5312.8 feet above sea level during the period when measurements were being taken.

Table 5: Groundwater Elevations* (in feet above sea level)

Date	Wetland	Ditch	Parking Lot
02/22/00	5312.2	5317.2	5309.9
03/02/00	5311.1	5318.3	5312.3
04/27/00	5315.3	5317.9	5312.9
05/29/00	5312.8	5317.9	5313.7
05/30/00	5312.8	5317.9	5313.5
05/31/00	5312.8	5317.9	5313.3
06/02/00	5312.7	5317.9	5312.7
06/04/00	5312.7	5317.9	5312.2
06/18/00	5312.5	5317.9	5310.7
06/30/00	5312.9	5317.9	5310.6
07/23/00	5312.4	5317.7	5309.2
08/06/00	5312.3	5317.5	5308.7
08/29/00	5312.2	5317.4	5308.4
08/30/00	5312.1	5317.3	5308.3
09/01/00	5312.2	5317.3	5308.3
09/02/00	5312.2	5317.3	5308.2
09/05/00	5312.1	5317.3	5308.2
09/24/00	5311.9	5317.3	5308.1
10/08/00	5312.1	5317.3	5308.1
10/29/00	5312.0	5317.2	5308.1
11/26/00	5312.0	5317.2	5308.1
12/22/00	5312.0	5317.3	5308.1
01/10/01	5312.0	5317.3	5308.1
02/08/01	5312.0	5317.3	5308.1
03/06/01	5312.0	5317.4	5308.2
04/02/01	5312.0	5317.4	5308.2
04/28/01	5312.1	5317.6	5308.2

* Well locations are shown in Figure 1.

The design of a new roadway should allow as much sub-grade flow to enter the ponds as possible and should minimize the amount of runoff entering the pond from the roadway surface. Figure 4 shows a graphical representation of measured groundwater well levels over time.

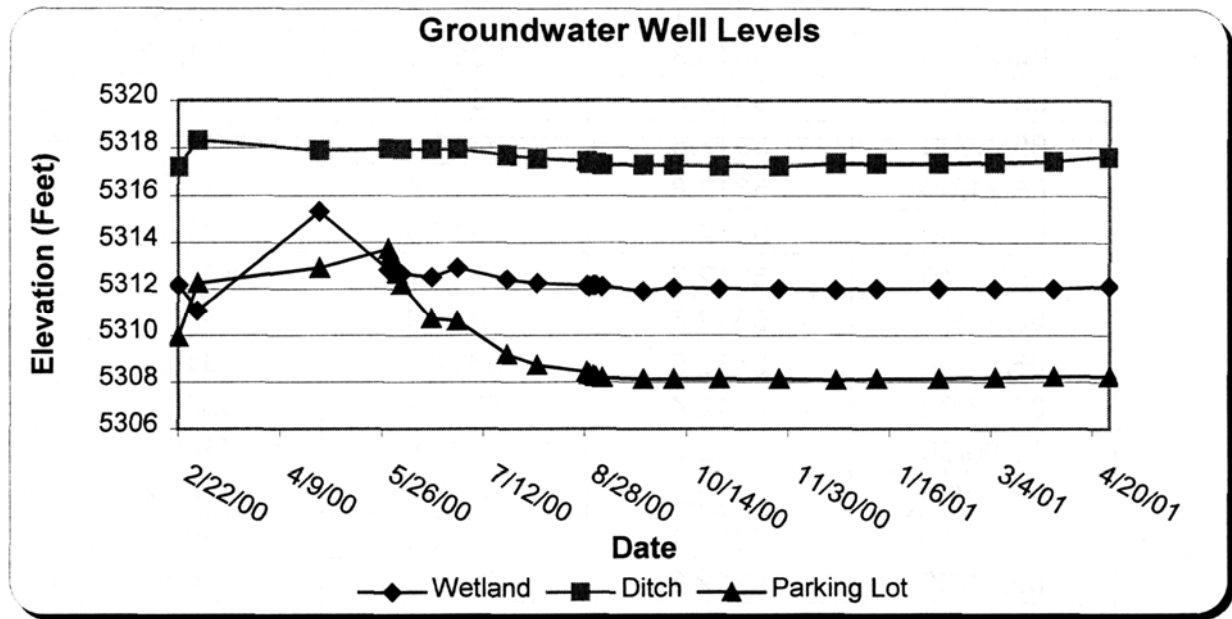


Figure 4: Comparison of groundwater elevations

5.0 Recommendations

Results of the water budget analysis indicate that current water levels in the primary ponds can be sustained without surface flow from Icebox Creek. This was confirmed during the experimental re-routing of Icebox Creek. However, history has shown that there has been an extended dry period when the pond water levels decreased enough to threaten the fishery. Icebox Creek also delivers high phosphorus loading, increasing the density of aquatic vegetation in the ponds. Therefore, a solution is needed that would normally allow Icebox Creek to be diverted around the ponds, but would allow the creek to flow through the pond system during dry conditions.

A possible approach would be to install a gate system that would normally be closed to divert Icebox Creek around Yates Ponds, but could be opened during periods of

inadequate groundwater flow. The hydraulic residence time for the pond system is approximately 10.6 days (Equation 2) when only accounting for groundwater inflow. This fact, along with the rapid reduction in algae observed during the experimental 1-year re-routing period, indicates that sustained increases in aquatic vegetation would probably not result from a short-term increase in nutrients during a temporary routing of Icebox Creek through the ponds.

$$HRT = V / Q * 86,400 \quad \text{Equation 2}$$

where

- HRT = Hydraulic Residence Time (in days)
- V = Water Volume in Ponds (in cubic feet)
- Q = Inflow (in cfs)
- 86,400 is a conversion factor

Another possible improvement would be to design and implement a small managed wetland system upstream of the pond inlet. A designed and managed wetland could be significantly more efficient in removing sediment and phosphorus than the first pond in the existing 3 pond system (Kadlec and Knight, 1996). With an effective wetland in place, the creek could be allowed to flow into the ponds during periods when subsurface flow is inadequate, without degrading the water quality of the system.

Finally, in order to minimize the nutrient and sediment loads from Highway 14A, two possibilities should be explored. First, it may be necessary to construct curb and gutter along the section of roadway adjacent to the main pond. The roadway runoff could be routed to either the small wetland or towards Raspberry Gulch, around the north boundary of the pond. An alternative to curb and gutter would be the use of a roadside trench system (St. Johns River Water Management District, 1992).

6.0 Conclusion

An 18-month field monitoring program was implemented to determine nutrient and water budgets in order to investigate the causes of excessive aquatic vegetation in Yates Ponds. Measurements of ortho-phosphorus as phosphate were used to develop the

nutrient budget. Phosphorus concentrations in the surface water and groundwater showed the same annual cyclic pattern. Phosphorus concentrations in surface water were found to be 51 % higher than those in groundwater.

Preliminary measurements indicated that the most significant components of the water balance at the ponds were inflows (surface water from Icebox Creek, spring flow, and groundwater), and outflow from the main overflow device. Inflows and outflows were measured for a 1-year period to develop the long-term water budget. Sources of inflow from groundwater and spring flow were estimated as the difference between surface inflow and outflow. Results of the water budget showed that current pond water levels could be maintained without surface inflow for the hydrologic conditions present during the study.

Turbidity measurements were used to estimate sediment loadings into the pond system. The observations indicate that sediment is not a problem under normal streamflow conditions. Periods of significant sediment loads into the pond are probably of very short duration, and are associated with sediment from local roadways and sediment transported during large rainfall events.

To determine whether groundwater and spring flow were adequate to sustain water levels in the ponds, Icebox Creek was diverted around the ponds. During the diversion period, water levels inside the pond remained constant. A decline in aquatic vegetation density inside the pond was also observed during the diversion period.

Recommendations include a gate system to allow surface flow from Icebox Creek to enter the pond during periods when subsurface flow becomes inadequate to maintain water levels. A constructed wetland system upstream of the pond inlet is a second alternative. The wetland would allow Icebox Creek to continue to flow into the pond, while significantly reducing the nutrient load from the creek. Curb and gutter may also need to be constructed along the pond edge to minimize the nutrient and sediment loads from Highway 14A.

7.0 References

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Date	PO ₄ ³⁻ (mg/l)				Turbidity (FAU)			Flow (gpm)			Groundwater (ft)			Temperature (°C)			
	Location				Location						Well Location			Location			
	U/S Wetland	D/S Wetland	Spring	Outlet	Icebox Creek	Spring	Outlet	Surface Inflow	Total Outflow	Ground Water	Wetland	Ditch	Parking Lot	U/S Wetland	D/S Wetland	Spring	Outlet
02/22/00	0.44	0.46	0.27	0.58	9	2	1				5.25	1.93	6.69	8	5	10	7
03/02/00	0.79	0.47	0.61	0.67	2	0	0				6.35	0.82	4.35	8	5	11	6
04/27/00	0.50	0.71	0.40	0.51	10	3	3				2.10	1.25	3.70	6	6	10	7
05/29/00								1149	2119	970	4.60	1.20	2.90				
05/30/00								1160	2087	927	4.60	1.20	3.15				
05/31/00								1207	1718	512	4.60	1.20	3.35				
06/02/00								938	1253	315	4.70	1.20	3.95				
06/04/00								933	1345	411	4.75	1.20	4.40				
06/18/00	0.45	0.17	0.27	0.20	4	0	0	337	1285	948	4.90	1.20	5.90	7	7	8	12
06/30/00	0.21	0.23	0.14	0.24	2	1	2	334	1083	749	4.50	1.20	6.00	15	15	12.5	16
07/23/00								314	1029	716	5.00	1.45	7.45				
08/06/00	0.22	0.17	0.16	0.14	8	0	0	462	895	433	5.15	1.60	7.90	9	10	12	12
08/29/00	0.15	0.15	0.18	0.11	0	0	0	18	377	359	7.25	1.70	8.20	10	10	12	13
08/30/00								20	380	359	5.30	1.80	8.30				
09/01/00								16	382	367	5.25	1.80	8.35				
09/02/00								15	362	347	5.25	1.80	8.40				
09/05/00								14	375	361	5.30	1.85	8.45				
09/24/00	0.27	0.17	0.15	0.19	3	3	5	9	363	354	5.50	1.85	8.50	5	6	11	9
10/08/00	0.32	0.24	0.19	0.22	2	0	1	5	331	326	5.35	1.85	8.50	4	4	11	7
10/29/00	0.40	0.27	0.28	0.14	0	0	7	3	322	319	5.40	1.90	8.50	8	9	11	10
11/26/00	0.49	0.18	0.10	0.33	1	0	4	0	201	201	5.40	1.90	8.50	2	1	7	4
12/22/00	0.53	0.28	0.35	0.48	1	1	3	0	276	276	5.45	1.80	8.55	1	1	7	4
01/10/01	0.68	0.42	0.52	0.59	1	0	4	0	241	241	5.40	1.80	8.50	1	1	7	3
02/08/01	0.47	0.27	0.33	0.41	2	1	3	0	203	203	5.40	1.80	8.50	3	2	8	6
03/06/01	0.21	0.25	0.19	0.14	4	3	4	0	197	197	5.40	1.75	8.45	4	4	11	10
04/02/01	0.20	0.20	0.16	0.22	3	3	4	0	264	264	5.40	1.70	8.40	6	6	11	10
04/28/01	0.17	0.18	0.14	0.16	4	3	3	0	377	377	5.30	1.50	8.40	7	7	11	11
05/17/01	0.15	0.14	0.10	0.11	2	1	2							8	9	11	11
06/01/01	0.08	0.11	0.08	0.07	2	1	3							10	10	11	14
06/17/01	0.04	0.14	0.07	0.15	2	2	3							9	10	11	15
07/04/01	0.13	0.15	0.10	0.13	4	2	5							10	11	12	16

7/18/11	0.24	0.20	0.14	0.13	1	3	5				10	11	12	14
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